A Re-examination of the Light scattered by Gases in respect of Polarisation. I.—*Experiments on the Common Gases.*

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Introduction.

In an earlier paper* I showed that the light scattered by gases free of dust was not perfectly polarised, but that a residual defect of polarisation remained, which was characteristic for each gas. This was an entirely new field of investigation, and the experimental methods for detecting and measuring a very minute effect had to be worked out. As is the universal experience, many improvements suggested themselves in the course of the work, and after an interval it was decided to repeat a part of it again, with many modifications in detail, designed to give the most accurate numerical results that seem at present obtainable. This has now been done, with results which, speaking generally, confirm the earlier investigation, except in one important particular.

It was decided to limit the present investigation to the permanent gases, thus excluding the vapours of organic substances. The latter are inevitably absorbed by the blacking which it is necessary to use on the inside of the vessel, and when the substance under investigation is changed they may come off and give rise to contamination. Moreover, there is the tendency of some of these substances to form fogs under the influence of light. It would have been premature to include them in a first attempt to establish accurate methods. Pioneer determinations were given in the former paper, and are believed to be substantially correct.

The great difficulty in this work is the feebleness of the light. In considering how the former methods could be improved upon, it appeared that the chief possibility remaining open was to use a broader beam of exciting light, so as to photograph laterally a deeper layer of gas giving secondary emission. This entails a much larger vessel than that used before, not only to admit the larger beam, but also for the avoidance of scattered light. The vessel formerly used, it will be remembered, was in the form of a cross, the primary beam passing along one direction and the lateral scattering being observed in the perpendicular one. If the conditions are to remain as favourable for the

* 'Roy. Soc. Proc.,' A, vol. 95, p. 155 (1918).

avoidance of stray light, it is necessary to preserve geometrical similarity. The beam formerly used was only $\frac{1}{2}$ inch broad. It was desired in the present work to use a 4-inch beam. This would require the vessel to be magnified eightfold in linear dimensions, which would mean 1 foot diameter and arms of 12 feet and 18 feet. These dimensions are practically prohibitive on the laboratory scale, and it was necessary to cope with conditions much less favourable than before for the avoidance of stray light. After much experimenting, the desired result was attained in a vessel of moderate dimensions.

§ 2. *Black Background.*

The most important point to be attended to is the way in which the far end of the vessel (away from the camera) is constructed. This necessarily forms the background, against which the faint light under investigation is to be observed, and it must be arranged so as to send back exceedingly little stray light. The requirements are very severe. The back surface must not be luminous enough to produce the faintest photographic impression in an exposure of 24 hours or more with the most sensitive plates and the most rapid lens, and this in the neighbourhood of the beam from a powerful arc.

No ordinary blacking of the surface was found adequate, having regard to the comparatively short distance at which it had to be placed. The best that can be done in this way, so far as my experience goes, is to smoke the surface over a gas-jet, but this is far from good enough. Blacking of any kind diffuses some light in all directions, and, amongst others, in the particular direction which is harmful, *i.e.*, towards the lens. On the other hand, a perfectly polished surface reflects the light in one direction only, and this may be arranged to be a direction where it is harmless.

The first expedient tried was to place a piece of ruby glass obliquely in the tube, so that the reflexion from it would be towards the side wall of the vessel. This was a great improvement when compared with blacking, but suffered from several defects.

Ruby glass is full of small particles to which the colour is due. These scatter some light diffusely from the surface, and this light was found to be more actinic than might have been expected, probably because it comes from a layer so near the surface that absorption of blue light is incomplete. What is to be aimed is, of course, a glass which is so coloured as to absorb and get rid of any actinic light which enters it, without scattering anything back. A study of various glasses showed that deep green (coloured, I believe with chromium), combines photographic opacity with absence of scattering. Further, it was found that a fired surface was preferable to any polish that could be obtained. These conclusions were established by holding the glasses

to be tested directly in a very powerful beam, and estimating the photographic importance of the scattered light by a blue glass held over the eye.

But a single oblique plate of glass has another defect. The surface reflects an appreciable percentage of the incident light to the side wall, and this light, together with any that may fall on the side wall directly, is partially reflected back by the glass plate, and thus gets back to the camera. Even this effect was appreciable. It was met by using a curved horn blown from green glass by Messrs. Powell. Any light which fell into the mouth of the horn was reflected internally from side to side and soon lost completely (fig. 1). The internal blown surface was very good for the purpose.

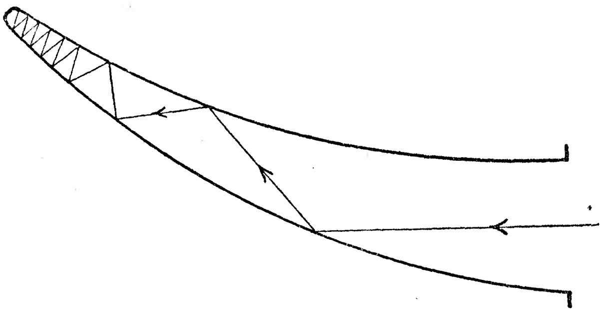


FIG. 1.

The horn was covered outside with black paint, and wrapped in black cloth as an additional precaution. Such a background appears extraordinarily black, even when a powerful arc shines right into it. It is instructive to compare it under these conditions with a piece of black velvet, which seems by comparison a brilliant object.

§ 3. *Limitation of Photographed Area.*

Another point to be considered is how the illuminated area which is photographed on the plate is to be defined or limited. In the former work this was done by taking advantage of the limited cross-section of the beam itself, the outline of which was focussed upon the plate. With a great increase of the depth illuminated, this is no longer satisfactory, for if the nearer parts of it are in focus, the distant ones cannot be so, and the diffuse edges of the two oppositely polarised images would overlap, unless indeed these two images were widely separated, which is undesirable on other grounds. For this reason, a rectangular diaphragm was used, which was backed by the layer of luminous gas. A rather larger diaphragm was placed nearer the primary beam and protected the final diaphragm from any danger of being grazed by the primary beam, which would have produced a very harmful illumination of its edges.

§ 4. *Polarising Prisms.*

In the former investigation, the two images formed by a double image prism suitably oriented were assumed to have intensities in the same ratio as the polarised components of the scattered light. These intensities were approximately equalised by an absorbing screen placed over the plate, to cover the denser image, and the measurement consisted, briefly, in finding an appropriate screen out of a series of graduated density, the absorbing power of which was known. This method is advantageous in the saving of light, but obviously does not lend itself very well to anything beyond rather rough measurements. In the present work, a large nicol was employed in front of the double image prism, to equalise the two beams, according to a method used by Cornu and by my father, for examining the polarisation of the sky. This method has the great advantage of readily allowing continuous adjustment, as close as may be desired. The objection to it is the loss of light, but this could be tolerated with the better illumination now used, and the longer exposures which were practicable when the field of work had already been surveyed. The case of helium, however, is an exception in this respect, and will be treated separately.

Preliminary tests showed that, starting with unpolarised light, the double image prism did not produce two images of equal intensity within the desired limits of accuracy. Evidently, therefore, the ratio of intensities obtained with partially polarised light could not be taken as a true measure of the constitution of the light. Further, from other tests, there was reason to suspect that a nicol prism placed over the camera lens did not affect the two images according to the simple law of $\tan^2\theta$—indeed, with an oblique ended nicol, this is not to be expected; but the discrepancies seemed greater than anticipated. For these reasons, a method was used which avoids any assumptions about the behaviour of the polarising prisms.

This method depends on an empirical adjustment beforehand. Suppose, for instance, that we wish to determine whether the original polarisations have intensities in the ratio $1:n$. The nicol must be set in such a position that it would equalise the intensities under these circumstances. To set the nicol, unpolarised light from a steady source is used, but, by covering up one of the images with a screen near the plate, we may expose them separately, and thus arrange for the horizontally vibrating component to receive n times as much light as the vertically vibrating one. This is most conveniently attained by diaphragming the camera lens to $1/n$th aperture between the exposures. The diminution of aperture, it is true, reduces the light *after* passing the prisms, but, for a given exposure (one

polarisation only), its effect is obviously the same as if some means of reducing the original source to $1/n$th intensity had been employed during that exposure.

It was found most convenient in practice not to cover one of the images, in view of their small size and nearness together, but to make two separate exposures on different parts of the plate, each showing a pair of images. The pair made with the smaller aperture was, of course, the less intense. The nicol was adjusted until the weaker image of one pair was made equal to the stronger image of the other pair, using diaphragms in a given ratio. The order of the exposures and the displacement of the plate was, of course, arranged so as to bring these two images to be equalised side by side on the negative.

It was found that the brightest image, *i.e.*, the strong image from the large aperture, tended to produce halation on the plate, which would, of course, give rise to systematic error. This was only partly got rid of by using backed plates, and it was necessary, therefore, to prevent the strong image (which is not used in the measurement) from falling on the plate at all. This was achieved by a suitable screen or stencil of thin ebonite in contact with the film. The obscuring strips of ebonite were spaced $\frac{3}{4}$ inch apart, the exact distance through which the plate was moved when making a new pair of exposures (four such pairs were made on each plate). Thus in each case there was an ebonite strip in position to obscure the strong image, leaving the other three.

The method of calibration adopted is subject in addition to a source of error which was not sufficiently appreciated when this method was designed. The error arises from *false light, i.e.*, light reflected or scattered from the various surfaces of the lens and polarising prisms. This is of no practical importance when the only images which reach the camera are of approximately equal brightness, as in making the adjustment with light scattered by a gas. When, however, the calibration is made, the strong image is surrounded by a glare which extends around it with intensity diminishing as we proceed outwards. Although the strong image itself is screened off by the ebonite strip, the glare around it reaches the plate, and is superposed in varying degrees on the two images of much less intensity which are to be equalised, thus making the apparent equality illusory. It appears impracticable to eliminate this source of error altogether, and all that can be done is to allow for it as well as possible. The nicol is set so as to give the best extinction attainable for the weaker image, and the calibration process carried out much as usual, except that the smaller diaphragm is now to be chosen, so that the strong (now the only) image given by it is equal in

intensity to the false light which falls where the weaker (now extinguished) image for the larger diaphragm would have been. Practically, the exact size of diaphragm must be found by interpolation. In this way it was determined that the weaker image had a spurious apparent intensity equal to 0·677 per cent. of the stronger one, when its intensity should have been zero. It was assumed that this spurious addition remained the same for all the not very wide range of angular positions of the nicol that were used, and a subtractive correction was applied accordingly. This procedure is not wholly satisfactory, but the need for it was not discovered until the present section of the work had been considered finished; and no better method of making the correction suggested itself.

This method of calibrating by two exposures requires the use of a light whose constancy may be depended upon. A "Pointolite" lamp supplied by a storage battery *exclusively reserved for it*, answered this purpose.

§ 5. *Comparison of Photographs.*

In the earlier work ordinary photometric methods were used for testing whether the two images given by the double image prism had been successfully equalised, so as to give equal photographic effect. I was dissatisfied with the sensitiveness of this method, which as I applied it, at least, did not give a sharp enough test of equality.

In later experiments a photo-electric method of comparison has been used which has proved in practice far easier and less fatiguing. The arrangements are shown in fig. 2. At A is a "Pointolite" lamp (enclosed tungsten arc) focussed by a lantern condenser, B, on a slit, C, in the metal plate, D. This slit measures 3×1 mm. at the upper surface of D, but the four edges which define it are bevelled, so as to give a larger aperture below, to allow passage to the diverging cone of rays. These rays fall on a photo-electric cell, E (potassium, in helium at a few mm. pressure) in circuit with a dry battery giving about 150 volts and a sensitive high resistance moving coil galvanometer. The negative under examination is placed film downwards on the plate, D, which is embedded flush in the top of a box enclosing the photo-electric cell, and protecting it from stray light (see the plan fig. 3, lettered to correspond with fig. 2). The images to be compared, HH, fig. 3 are brought successively over the slit, and the galvanometer deflection noted. There is an adjustable guide, FF (both figs.) for that edge of the negative which is perpendicular to the slit, and to the long dimension of the images. In changing to and fro from one image to the other, the correct central position over the slit is judged by eye, assisted in some cases by suitable ink dots on the negative (fig. 3). The point to be noted is which image gives the smaller

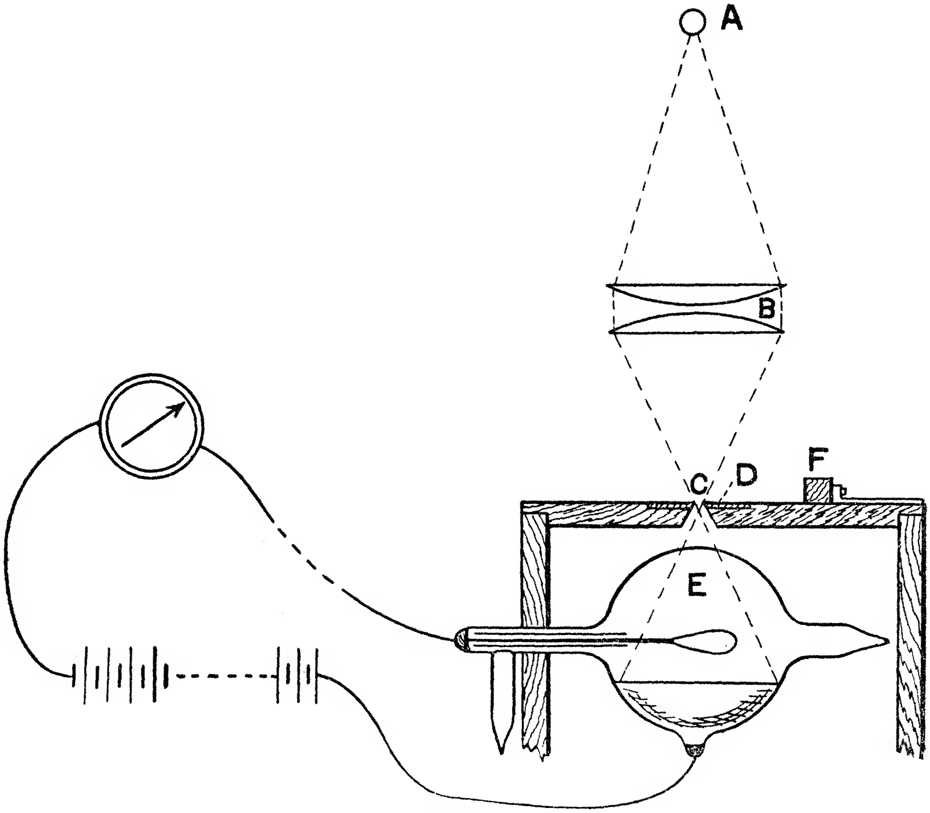


FIG. 2.

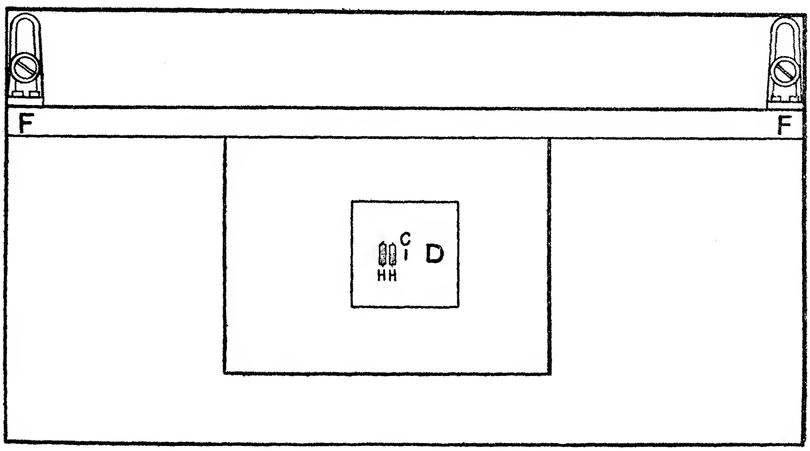


FIG. 3.

deflection, and is the more opaque. A number of alternate readings were taken and were usually in good agreement. The "Pointolite" lamp was of the "fixed focus" pattern; the more usual pattern, with a tungsten knob which moves as the lamp heats up, was found decidedly less satisfactory for this work.

The photometric arrangements ultimately adopted were very satisfactory, and with a given pair of images results which were much more concordant among themselves than those which were obtained when a second pair, taken under (apparently) the same conditions was substituted.

It was absolutely necessary to use for the "Pointolite" lamp a storage battery which was not in use at the same time for other work. When induction coils, motors, etc., were being used on the same battery hopeless irregularities were introduced.

The two images to be compared necessarily occupy different positions on the plate, and it is necessary, therefore, that the latter should be as uniform as possible, if accurate results are to be obtained. I tested ordinary photographic plates in this respect by fogging them by a few seconds' exposure to a distant candle, and after development, testing the opacity of different parts with the photo-electric apparatus. A serious lack of uniformity was found, and it was almost always easy to determine which of two closely contiguous portions was the denser: what was worse, there were occasional *precipices* on the plate, where very sudden differences of opacity occurred. Though it would be theoretically possible to eliminate this source of error by repetition, yet the process would have been most tedious and unsatisfactory. Eventually, at the suggestion of my friend, Prof. R. W. Wood, I used plates coated on plate glass, which proved very much more uniform, when tested in the same way. It appears that the irregularities of ordinary plates are due in the main to want of flatness in the glass, which causes the film to be of variable thickness. The plates used were specially prepared for me by the Kodak Company. The emulsion used was Seed 27 and Seed 30. The latter is the most suitable that I have been able to find for this work when great rapidity is the main essential.

Special attention has been paid to the question of the best density for the photographs. The object is to discriminate as closely as possible between two negatives of nearly equal density. If the exposure is very short, then, in the limit, neither image has perceptible density, and no discrimination can be made. Again, if the exposure is very long, both images are very dense, the total galvanometer deflection very small, and the difference of deflections imperceptible. An intermediate density is most favourable. Its value was investigated by a "Spurge sensitometer" kindly lent me by

Sir William Abney. This is, in effect, a collection of pinhole cameras with progressively increasing apertures, each having an area 1·25 times that of its predecessor. One of the plates to be used was exposed in this apparatus, to a diffused light and a series of graduated densities obtained. They were examined with the photo-electric cell, and it was found that beginning with the weakest image (barely visible), the change of deflection from one density to the next increased, reached a maximum, and then diminished. As might be expected, the difference remained fairly constant over a considerable part of the series in the neighbourhood of the maximum. If the opacity was such as to reduce the galvanometer deflection to 0·85 times the value obtained on the unexposed part of the plate, the best sensitiveness to change of exposure was practically attained, and continued nearly unaltered up to much denser exposures, such as would reduce the deflection to 0·3 of the bare film value. The densities used were kept within this range, and owing to the long exposures required in many cases, they were usually nearer the lower limit of opacity.

In using null methods of measurement, such as the balance or Wheatstone bridge, it is generally found best not to aim at precise adjustment, but to interpolate between positions on either side of the neutral point. In the present case where each observation involves a long photographic exposure, this is doubly advisable, for otherwise valuable material obtained with much trouble would be needlessly rejected.

Preliminary tests were made to locate the neutral point approximately, and then two positions, usually 0·5 degree on either side of it, were selected for taking the photographs. The departure from balance was measured on an arbitrary scale by the difference in galvanometer scale divisions for the two approximately equal images, when these were examined in the photo-electric apparatus. This difference was positive for one set of photographs, negative for the other. By interpolation the zero position was found.

§ 6. *Supply of Gas.*

The programme for accurate determinations of the ratio of polarisations included hydrogen, nitrogen, air, oxygen, carbon dioxide, and nitrous oxide.* All these, except air, were bought compressed in steel cylinders. In this way the use of acids, highly undesirable in the neighbourhood of valuable calcite prisms, was avoided. The apparatus was in each case exhausted, and filled up with the gas, and while the exposure was proceeding, a constant stream at the rate of about 500 c.c. per minute was maintained. In this way the gas actually under illumination was changed once a minute which

* Work on the rare gases will be described later.

greatly diminished any risk of error from the formation of a fog under the influence of light. No indication was ever noticed that this had occurred. The gas stream was dried with phosphorus pentoxide and filtered through closely packed cotton wool.

Careful consideration of the amount and character of impurity liable to be present in the commercial gases clearly shows that no sensible error could arise from this cause.

§ 7. *Arrangements for Observing Scattering.*

The apparatus (figs. 4, 5, 6) is shown natural size, the main brass tube, A, being 4 inches diameter. The rectangular ribbed castings, BC, were screwed and soldered to it. The exciting beam enters through the plate glass window at D. It is confined by the rectangular diaphragms F, G, and H. After crossing the main vessel and entering C it falls on the window E, smoked inside. The centering can be verified by observing the patch of light on this window.

The laterally scattered light was observed through the window, M. On looking through this window the diaphragm, L, was seen as a rectangular patch of bluish light on a black ground. The larger diaphragm, K, served merely to reduce the stray light that fell on the *edges* of *l*, and which tended to make these edges appear luminous as seen from M. W is the green glass horn already described. Its flat ground flange was cemented to the brass flange terminating H.

To avoid strain on the cement, W was further held in position by a metal ring, provided with three studs and nuts. A rubber ring acted as cushion to distribute the pressure uniformly on the outside of the glass flange.

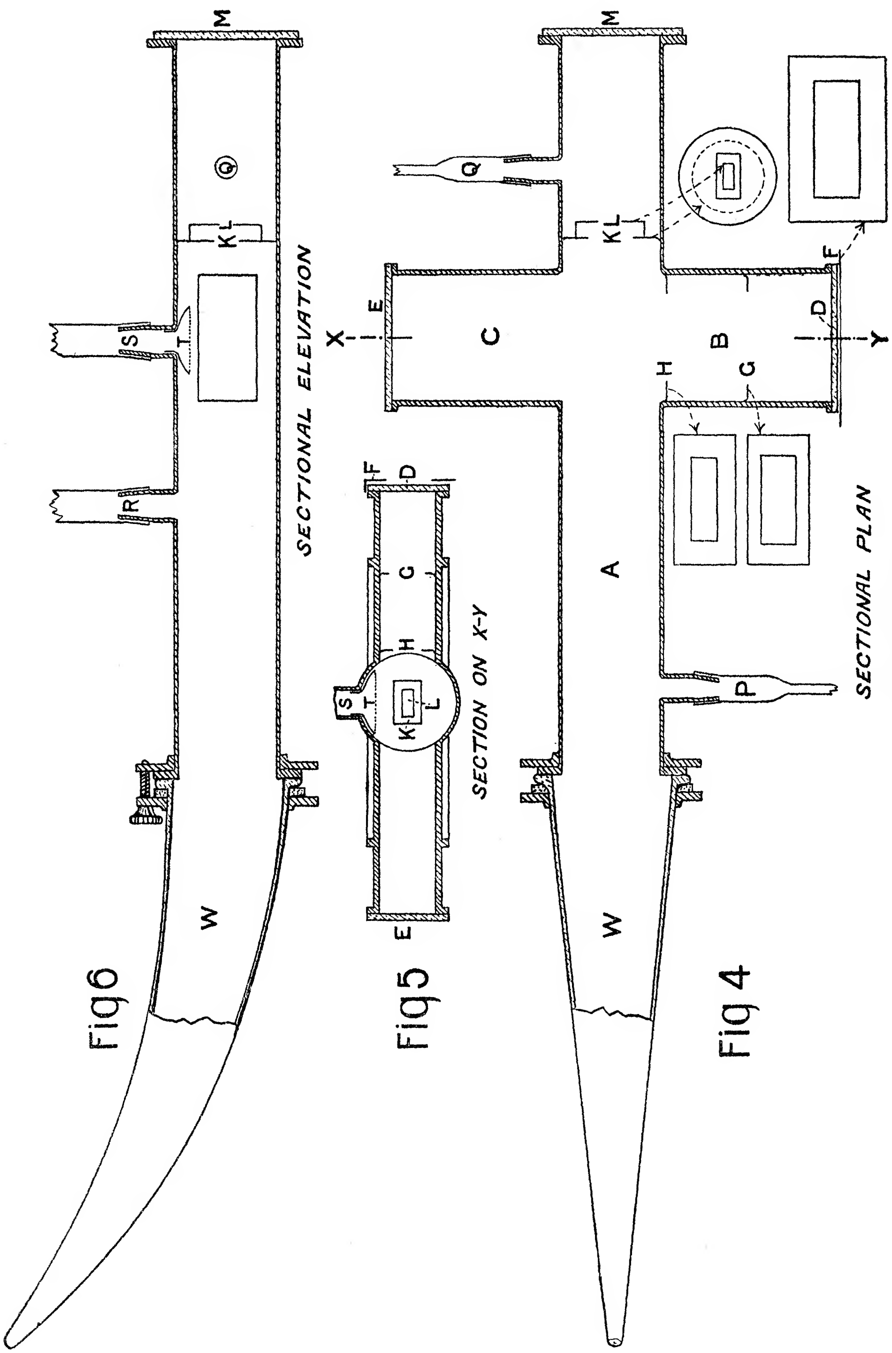
P and Q are for the entrance and exit of a stream of gas.

R and S are the ends of the charcoal vessel attached to the apparatus for the purification of helium. T is the gauze distributor which is used in connection with the charcoal purification. The description of this part of the work is deferred for a later paper.

The metal parts were soldered together and covered with two successive coatings of stoved enamel, as used for bicycles, etc. The glass parts were attached to the metal by a cement of pitch and gutta-percha, somewhat harder than Chatterton's compound.

The air-tightness attained was remarkable. The vessel was exhausted and left in communication with the charcoal and with a MacLeod gauge. No leakage amounting to $\frac{1}{10}$ mm. had occurred after the lapse of two months.

As before, a hand-feed lamp was used with positive carbon horizontal and negative only slightly inclined to the vertical. "Kinarko" cinematograph



Scale about $\frac{1}{7}$th natural size.

carbons were used with a current of 20 ampères. Considerable advantage was gained from the 200-volt supply instead of 100-volt used before. The carbons could be left some ten minutes before it became necessary to feed them up. The lens was an ordinary 4-inch lantern condenser, of Herschel's construction (convex meniscus near the light, combined with double convex). The light was placed in its focus by turning the lantern aside and observing the image on a distant wall. In this way, moreover, it was ascertained that the maximum divergence of the rays was within the permissible limits, three or four degrees from the axis. After leaving the lens, the beam passed through a water cell 2 inches thick, through which a continuous flow of cold water was maintained. It then passed through the outer diaphragm, F, into the apparatus.

The optical train for examining the scattered light is shown diagrammatically in fig. 7, the distances, however, being to scale.

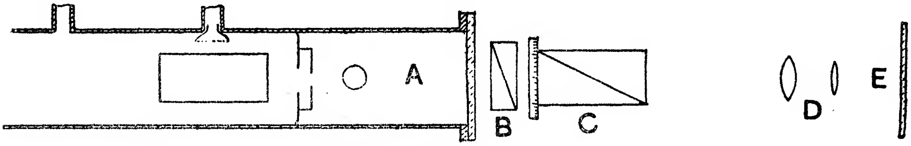


Fig. 7.

Scale about $\frac{1}{8}$th natural size.

B is the double image prism placed immediately in front of the window, A. It is of Iceland spar and quartz, the latter being used to secure direct vision for the point midway between the two images. The quartz is cut with its refracting edge parallel to the optic axis, so that no complication arises from the rotatory property. Quartz was used instead of glass, in order to transmit ultra-violet rays and for the same object cement was dispensed with.* No use was eventually made of extreme ultra-violet light, and I regretted that this construction had been adopted, as it gives rise to undesirable reflexions.

C is a Nicol prism of $1\frac{3}{4}$ inches aperture, very clear and transparent. Its angular position could be read to one-tenth of a degree.

D represents the Dallmeyer kinematograph lens, working at $f/1{\cdot}9$, the same as was used in the former investigation. E is the photographic plate.

The camera is not here described in detail. It was a special one, arranged for taking a number of exposures on the same plate. The distance through which the plate was moved vertically between exposures could be read on a scale attached.

* The ideal plan is to use spar for both prisms, according to Wollaston's construction. Material could not be obtained for this.

§ 8. *Optical Adjustments.*

The supports of the vessel were adjusted to make it level before the glass windows were put on. A spirit level could be put on the bottom of the parts CB. In the case of the tube AM it was sufficient to level the outside.

The slide on which the positive carbon of the arc was fed up was also levelled, and the beam was brought to the axis of CB, fig. 4, by observing its outline on the windows D and E.

With the green glass horn temporarily removed and a clear view through the tubular part AM, the polarising prisms and the photographic lens were readily adjusted to be in the axis of the tube, which was accurately at right angles to the part BC (fig. 4), which contained the primary beam.

The rectangular aperture L was focussed on the photographic plate. The image was, of course, duplicated by the double image prism, and the latter had to be placed so that the images had their directions of vibration respectively vertical and horizontal.

A preliminary examination of the behaviour of the prism made with the help of an accurately vertical glass plate at the polarising angle and a plumb line, had shown that the directions of vibration in the images were respectively parallel and perpendicular to the line joining them. It was therefore merely necessary to set the prism at such an angle that the line joining the two images was vertical, or, on a photograph, parallel to the edge of the plate, itself vertical during the exposure.

As explained in my former paper, very moderate accuracy in this adjustment is enough. If θ is the angular error, its effect on the intensity ratio depends only on θ^2.

For a similar reason, the line of vision need not be very exactly at right angles to the primary beam. This is fortunate, since considerations of intensity make a slight divergence in the primary beam inevitable.

The actual extreme divergence, three or four degrees from the axis, could do no harm. The same consideration shows that the greatest obliquity to be found in any of the rays collected by the photographic lens is well within the admissible limit.

We come now to one of the most important tests, that of the adequate blackness of the background. Evidently, if the back wall of the apparatus adds anything appreciable to the light scattered by the gas, serious error will be introduced; for the state of polarisation of this added light will not in general be the same as that due to the gas. To check this point, a photograph was taken with the apparatus exhausted to a small fraction of a millimetre of mercury, and the nicol away. Twenty-four hours' exposure was given,

extending over three working days. The plate was fully developed, and showed the two images of the rectangular aperture, L, *in outline*, this outline being due to light scattered by the edges of the diaphragm itself. The area inside the outline was in each case perfectly clear to the eye, and examination with the photo-electric apparatus showed no detectable difference between these areas and the clear film outside them.

In determining the intensity ratio corresponding to each position of the nicol in the manner already outlined (p. 438), it was considered undesirable to remove the optical parts from their places in the apparatus. The calibration was carried out *in situ*. It was necessary to back the rectangular diaphragm L with unpolarised light. This was done by taking off the glass horn and placing a diffusing screen of ground glass, combined with several thicknesses of tracing paper over the flange. Immediately behind this was placed a lens of about 12 inches focal length, with a "Pointolite" lamp in the principal focus. The lens was to ensure that the rays fell perpendicularly on the diffusing screen, but was perhaps scarcely needed.

The method of calibration requires diaphragms to reduce the lens aperture. If the ordinary photographic stops were used, it would be necessary to assume that every unit element of area in the full aperture contributed equally to the intensity. It was better to avoid this assumption, and the diaphragms were made in the form of a number of holes of about 1·5 mm. diameter spaced as nearly uniformly as possible over the full aperture. In no case was the number of holes used less than nine, so that a fair average of all parts of the area was secured. The holes were drilled in thin sheet zinc, and lightly countersunk on both sides with a tool held in the fingers, to remove the raggedness of the edges. The necessity for countersinking was regrettable as it slightly affected the diameter, which had therefore to be measured in each case. The diameters of the holes were determined to about 1 per cent. with a travelling microscope.

The "full aperture" used in the calibration process was a circular one turned in the same sheet zinc and measured in the same way. It was very slightly smaller than the full aperture of the lens as used for the actual exposures on scattered light. The latter formed part of the lens mount and was not conveniently accessible for exact measurement. No sensible error can be introduced by this procedure, the calibration merely requiring comparison of *apertures used in calibrating.*

The result of the calibrations was as follows :—

Reading of Nicol for equality.	Area (full aperture = 100).	Intensity, corrected for false light (full aperture = 100).
265 ·50	2 ·32	1 ·64
266 ·76	3 ·24	2 ·56
267 ·84	3 ·98	3 ·30
268 ·78	4 ·84	4 ·16
270 ·4	6 ·34	5 ·66
272 ·19	8 ·22	7 ·54
273 ·28	9 ·68	9 ·20
274 ·29	11 ·0	10 ·3
275 ·47	12 ·6	11 ·9
276 ·50	14 ·5	13 ·8
278 ·20	17 ·4	16 ·7

These values were plotted on a large scale for interpolation, and a smooth curve drawn through them, using a flexible lath. The values lie very well on the curve. Taking the areas as absolutely correct, the curve, as drawn, does not in any case give a position of the nicol differing by more than 0·15° from that experimentally determined. Thus the calibrations appear reasonably concordant, and free from unsystematic error. It is believed that there would not be much advantage in determining more numerous points on the curve or in repeating the determinations already made.

To judge from the evidence of the curve, it would seem that the errors which could be eliminated by doing so, are probably not more than about 3 per cent. on the value of the ratio in the second column. Larger systematic errors may be present, but repetition will do nothing to eliminate them.

§ 9. *Experimental Results.*

In the following Table, the first column of numbers gives the actual angular setting of the nicol required to equalise the images in each case, and the second the intensity of the weak component polarisation, taking the strong one as 100. This second column is obtained by placing the numbers of the first column on the calibration curve.

Gas.	Angle of Nicol degrees.	Intensity of weak component polarisation (strong component = 100).
Hydrogen	268 ·47	3 ·83
Nitrogen	268 ·72	4 ·06
Air.....................	269 ·78	5 ·0
Oxygen	273 ·6	9 ·4
Carbon dioxide ...	275 ·3	11 ·7
Nitrous oxide	277 ·5	15 ·4

Each angle arrived at is the result of about ten photographs, either side of the position of balance. In the case of air, for example, four photographs were taken at 269·5° and six at 270°.

For the former, the differences of density, in scale divisions of the galvanometer, were +18, +6·4, +12·3, +6. For the latter, −3·0, −4·2, −14·4, −4·0, −13, −10·6.

Each of these exposures lasted two hours in the case of air.*

The numbers given for air well illustrate the degree of concordance obtained from different photographs. It will be noticed that a rotation of the nicol of ½° shows the transition from too low to too high a reading very definitely. It is hoped that the final interpolated value is not more than 0·2° in error. I am confident that hydrogen and nitrogen are really in the order given.

The value of the ratio of intensities given in the second column is, of course, subject to the error of calibration, which may in some cases conspire with the error of setting. I shall be disappointed, however, if future investigation proves the results here given to be in error by much more than 5 per cent.

Note on the Influence of Temperature on the Rigidity of Metals.

By A. MALLOCK, F.R.S.

(Received June 9, 1920.)

In these 'Proceedings,'† I described some experiments on the influence of temperature on the value of Young's Modulus for various metals. The results showed that the more fusible the metal, the greater was the variation of the modulus with temperature, and suggested that, roughly, the decrement of the modulus for a given rise of temperature was equal to the ratio of the modulus at absolute zero to the melting temperature and a constant (*i.e.* $dM/d\theta = M_0/(\theta_n + \theta')$). Since Young's Modulus is a complex constant, involving both rigidity and volume elasticity, it seemed worth while to examine the temperature effect on rigidity alone, and with this object in view I have recently carried out‡ a further series of experiments on most of the metals previously tested.

The apparatus used was a torsion-balance, shown diagrammatically in fig. 1. A vertical rod, A, is suspended by a long fine wire, B, and the test

* For hydrogen six hours were necessary to get adequate density.

† A, vol. 95, pp. 429–437.

‡ At the Davy-Faraday Laboratory.